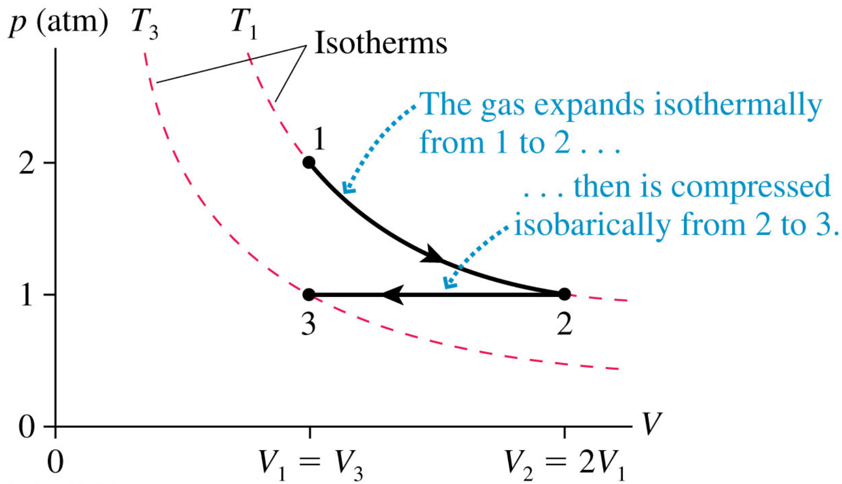
# *i.e.16.10: A multi-step process*

A gas at 2.0 atm pressure and a temperature of 200° C is first expanded isothermally until its volume has doubled. It then undergoes an isobaric compression until it returns to its original volume.

First show this process on a *pV* diagram. Then find the final temperature and pressure.



# Knight: Chapter 17

Work, Heat & the 1$^{st}$ Law of Thermodynamics

(*It's All About Energy, Work in Ideal-Gas Processes, & Heat*)

# Energy review...

- The *work-kinetic energy theorem* is...

$$\Delta K = W_c + W_{diss} + W_{ext}$$

$W_c = -\Delta U$

$W = \Delta E_{mech} + \Delta E_{th}$

$W_d = -\Delta E_{th}$

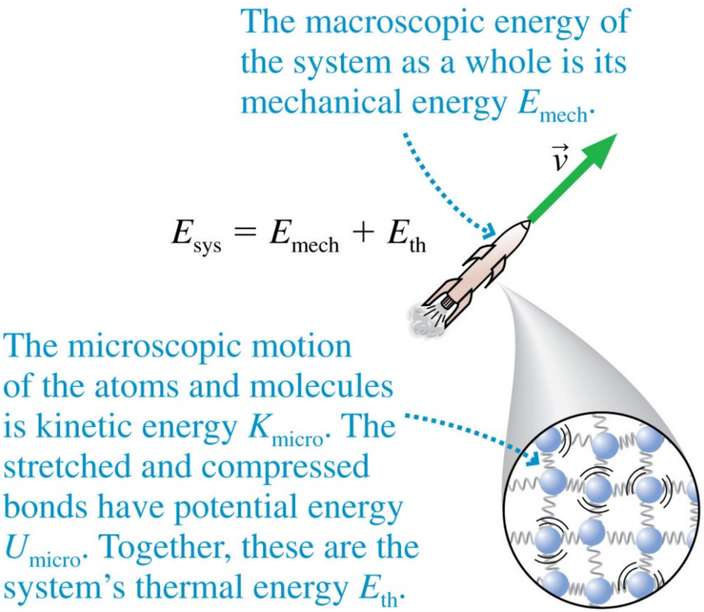
$\Delta K = -\Delta U - \Delta E_{th} + W_{ext}$

$\Delta K + \Delta U + \Delta E_{th} = W_{ext}$

$\Delta E_{mech} + \Delta E_{xt} = W_{ext}$

# *Energy review…*

- The *total energy* of a system consists of the *macroscopic energy* + the *microscopic thermal energy*.




$$\Delta E_{sys} = \Delta E_{mech} + \Delta E_{th} = W_{ext}$$

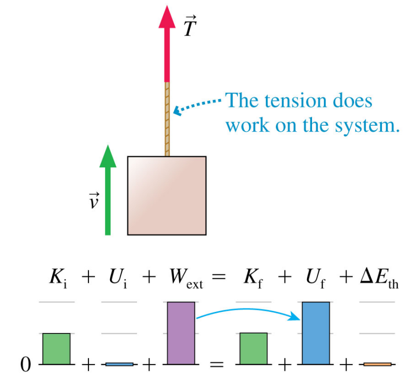
Notice:

The *total energy* of an *isolated system* is *constant* when $W_{ext} = 0$

# *Energy transfer by Work*

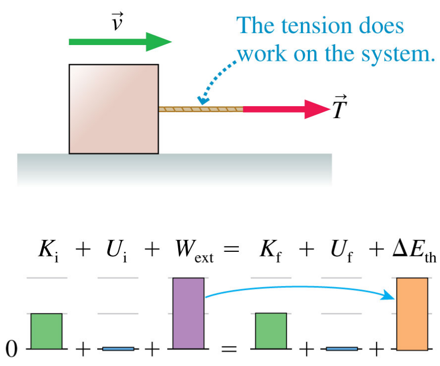
Doing work on a system *increases* its energy!

- Lifting a block with a rope at a *steady speed*.
  - The tension is an *external force* doing work $W_{ext}$.
  - Energy transferred into the system goes entirely into the *macroscopic potential energy*, $U_{grav}$.




The energy transferred to the system goes entirely to the system’s mechanical energy.

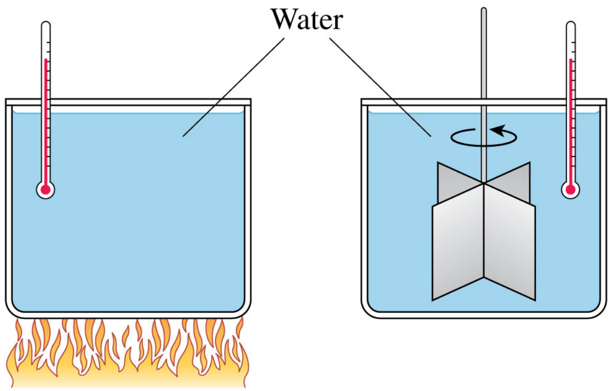
- Dragging a block with a rope at a *steady speed*.
  - The tension is an *external force* doing work $W_{ext}$.
  - Energy transferred into the system goes entirely into the *thermal energy of the object + surface system*, $E_{th}$.




The energy transferred to the system goes entirely to the system’s thermal energy.

# Work in Ideal-Gas Processes…

In the 1840s, James Joule showed that *heat* and *work*, are simply two *different* ways of transferring *energy* to or from a system.




The flame heats the water. The temperature increases.

The spinning paddle does work on the water. The temperature increases.

The final state of $H_2O$ is *exactly* the same in *both* cases!

# *Energy transfer by Heat*

- *Work, W,* is energy transferred in a *mechanical interaction*.
- *Heat, Q,* is energy transferred in a *thermal interaction*.
- The *complete* energy equation is…

$$\Delta E_{sys} = \Delta E_{mech} + \Delta E_{th} = W + Q$$

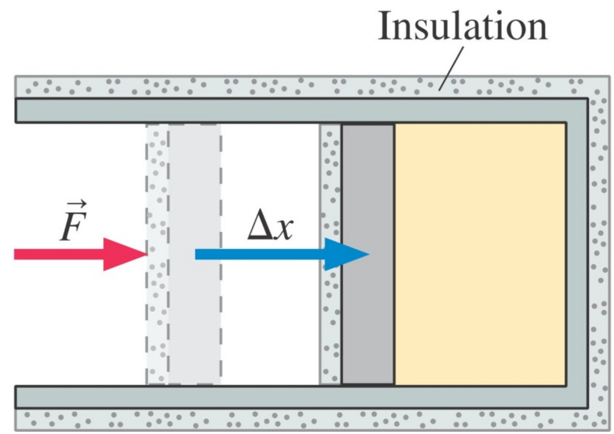
# *Quiz Question 1*

A steady force pushes in the piston of a well-insulated cylinder. In this process, the temperature of the gas

$W = F \cdot dx$

$f(t) = f$

$W \equiv$ Heat increase in heat




1. increases.
2. stays the same.
3. decreases.
4. There's not enough information to tell.

$Q + W = \Delta E_{mech} + \Delta E_{th}$

$W = \Delta E_{mech}$

$\uparrow W = \uparrow \Delta E_{mech}$

# *Work in Ideal-Gas Processes*

Consider a gas cylinder sealed at one end by a movable piston…

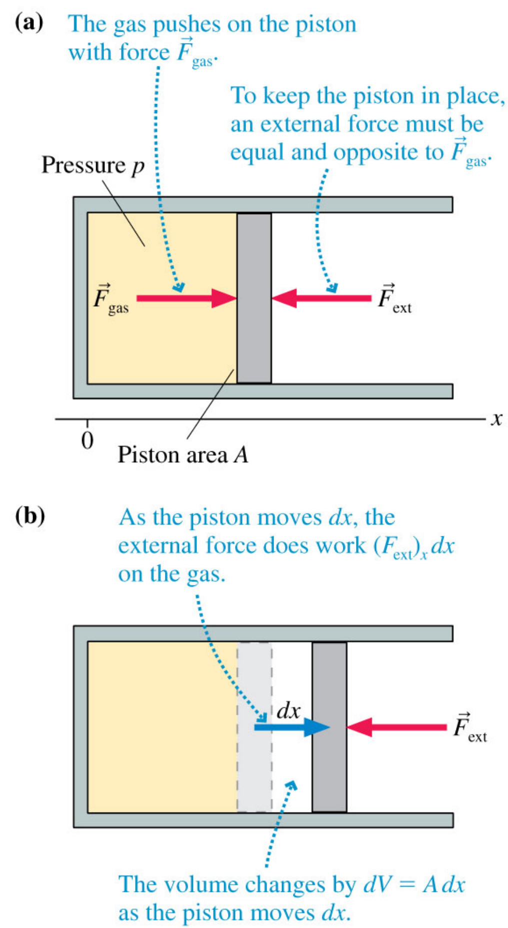
- The *external force* does work on the gas as the piston moves.

$$W_{ext} = \int_{s_i}^{s_f} \vec{F} \cdot d\vec{s} = \int_{s_i}^{s_f} F_{ext}\, dx$$

$$\vec{F}_{ext} = -\vec{F}_{gas}$$

$$= -\int_{s_i}^{s_f} F_{Gas}\, dx \qquad F_{gas} = pA$$

$$= -\int_{s_i}^{s_f} pA\, dx = -\int_{s_i}^{s_f} p\, dV$$

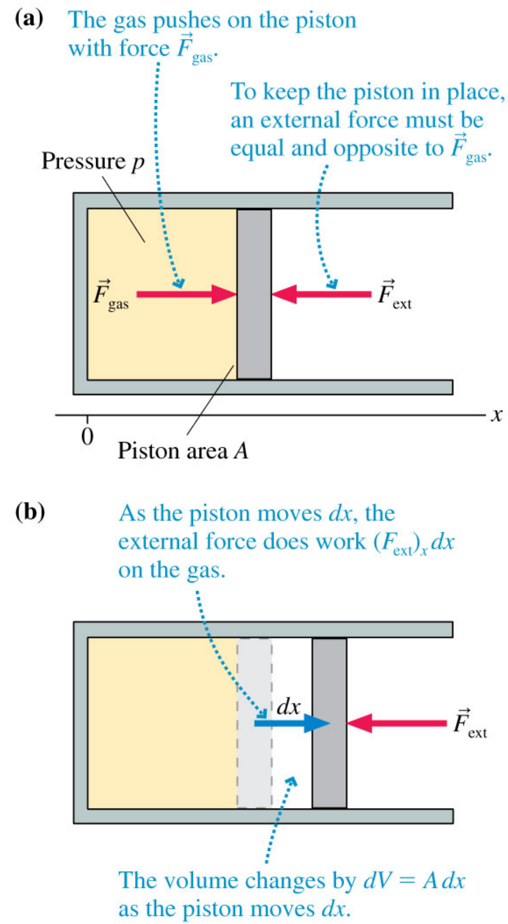


# Work in Ideal-Gas Processes

Consider a gas cylinder sealed at one end by a movable piston…

- The *external force* does work on the gas as the piston moves.

$$W = -\int_{V_i}^{V_f} p\, dV$$



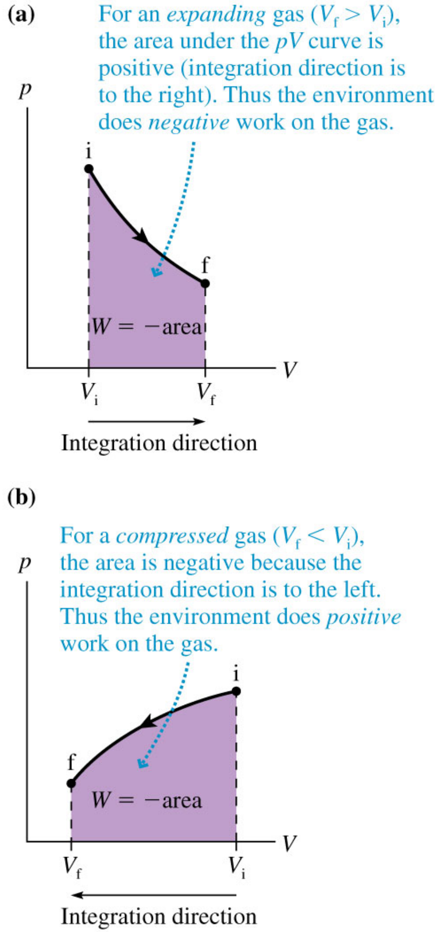

Notice:

The sign of the work is NOT an arbitrary convention, nor does it have anything to do with the choice of coordinate system.

# *Work in Ideal-Gas Processes*

- On a $pV$ diagram, the work done on a gas, $W$, has a nice geometric interpretation…

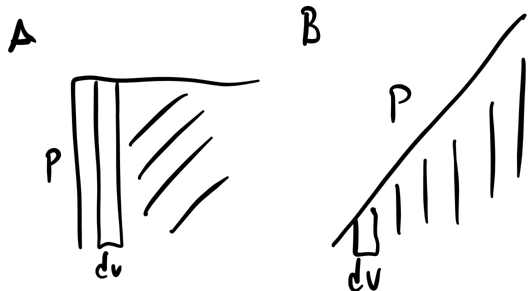
$W$ = the negative of the area under the $pV$ curve between $V_i$ and $V_f$.

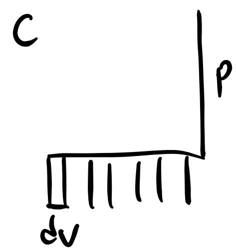


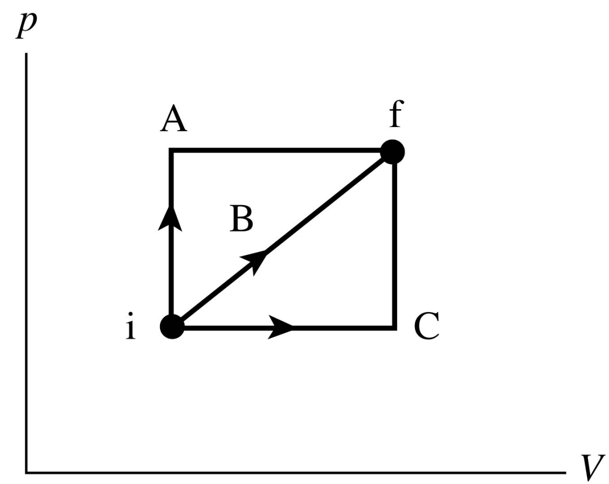
# *Quiz Question 2*

Three possible processes A, B, and C take a gas from state i to state f.

For which process is the magnitude of the work the largest?




1. Process A.
2. Process B.
3. Process C.
4. The work is the *same* for all three.

# Problem-Solving Strategy

PROBLEM-SOLVING STRATEGY 17.1 **Work in ideal-gas processes**

MODEL Assume the gas is ideal and the process is quasi-static.

VISUALIZE Show the process on a $pV$ diagram. Note whether it happens to be one of the basic gas processes: isochoric, isobaric, or isothermal.

SOLVE Calculate the work as the area under the $pV$ curve either geometrically or by carrying out the integration:

$$\text{Work done on the gas } W = -\int_{V_i}^{V_f} p\,dV = -(\text{area under } pV \text{ curve})$$

ASSESS Check your signs.

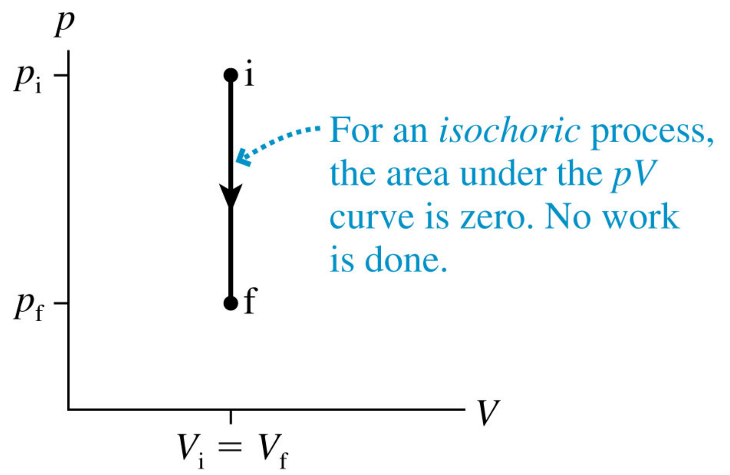
- $W > 0$ when the gas is compressed. Energy is transferred from the environment to the gas.
- $W < 0$ when the gas expands. Energy is transferred from the gas to the environment.
- No work is done if the volume doesn't change. $W = 0$.

Exercise 4

# *Work Done on an Ideal Gas…*

In an *isochoric process*, the work done on the gas is…

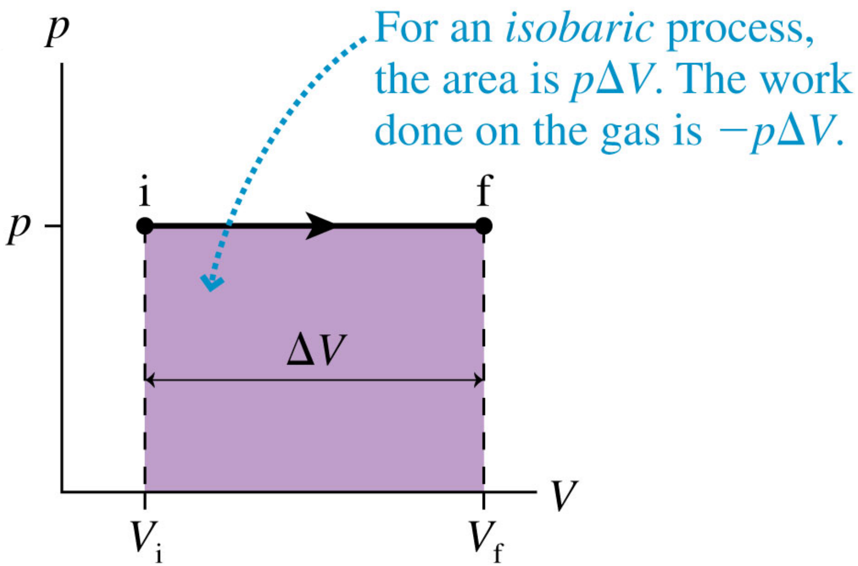
$$\boxed{W = 0 \qquad \text{(isochoric process)}}$$



# *Work Done on an Ideal Gas…*

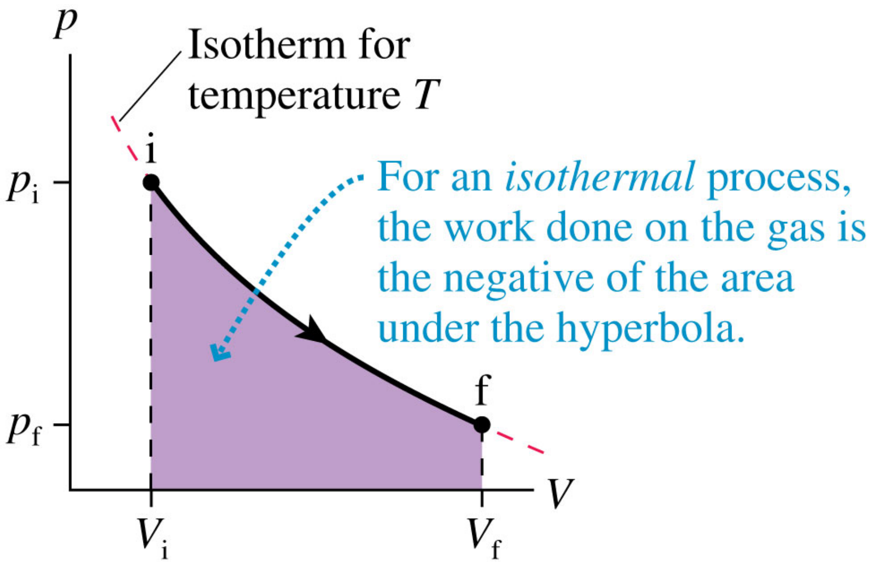
In an *isobaric process*, the work done on the gas is…

$$W = -p\Delta V \qquad \text{(isobaric process)}$$



# *Work Done on an Ideal Gas…*

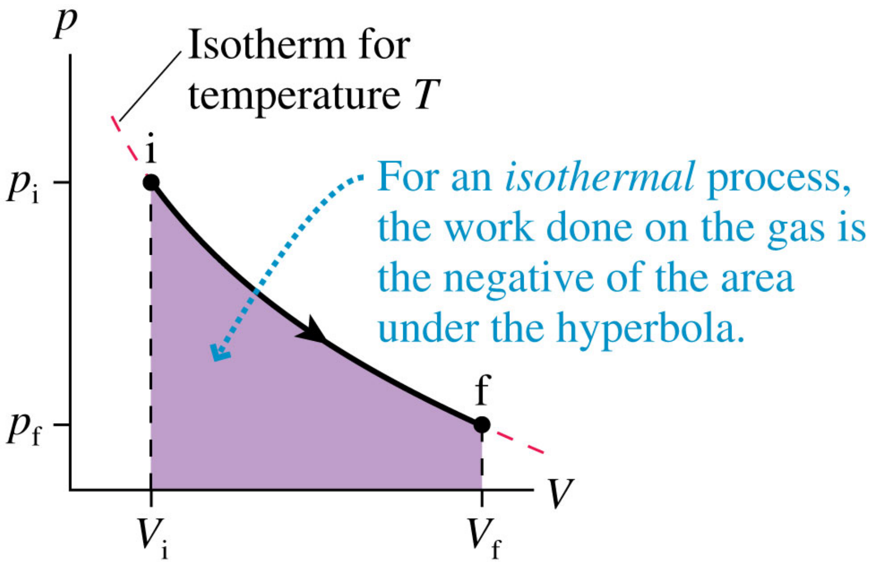
In an *isothermal process*, the work done on the gas is…



# *Work Done on an Ideal Gas…*

In an *isothermal process*, the work done on the gas is…

$$W = -nRT \ln\left(\frac{V_f}{V_i}\right) \qquad \text{(isothermal process)}$$



# i.e. 17.2: The Work of an Isothermal Compression

A cylinder contains 7.0 g of nitrogen gas.
How much work must be done to compress the gas at a constant temperature of 80° C until the volume is halved?

# Work in Ideal-Gas Processes…

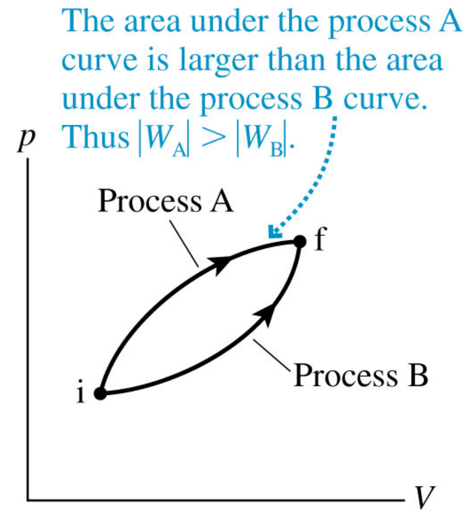
Figure (a) shows 2 different processes that take a gas from an initial state i to a final state f.

Notice:

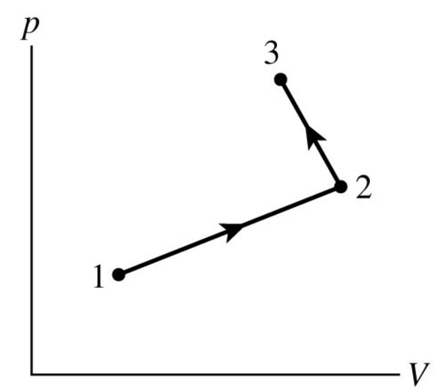
- The work done during an ideal-gas process *depends on the path followed through the pV diagram*.

- During the multistep process of figure (b), the work done is *NOT* the same as a process that goes directly from 1 to 3.

**(a)**




**(b)**



# Heat, Temperature, and Thermal Energy

***Thermal energy, $E_{th}$…***

- is an energy of the system due to the motion of its atoms and molecules.

***Heat, Q…***

- is *energy transferred* between the system and the environment as they interact.

***Temperature, T…***

- is a *state variable* that quantifies the "hotness" or "coldness" of a system.

A *temperature difference* is required in order for heat to be transferred between the system and the environment.